Technological Forecasting & Social Change 143 (2019) 76–84

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Impacts of climate change on water resources and grain production

Shibao Lu[a], Xiao Bai[b,*], Wei Li[a], Ning Wang[a]

[a] School of Public Administration, Zhejiang University of Finance and Economics, Hang Zhou 310018, China
[b] School of Finance, Zhejiang University of Finance and Economics, Hang Zhou 310018, China

ARTICLE INFO

Keywords:
Climate change
Water resources
Grain production
C-D-C model
Analysis of the correlation

ABSTRACT

Climate change impact assessment has become a universal concern and attracted more attentions all over the world. The climate change has an increasingly serious impact on water resources and grain production. Strengthening scientific research in relevant fields of climate change and enhancing grain production in order to adapt to climate change is of vital significance to guarantee food security, improve farmers' income and maintain social stability. This paper constructs a new economic-climate model based on the original Cobb-Dougla (C-D) production function by adding climate factors, and empirically analyzes the impacts of climate change on grain yield and illustrates regional differences. Constraints of water resource restriction on agricultural yields and agricultural planting structure are also proposed. Based on the analysis of the correlation between climate change and grain yield, the relationship between the use of irrigation water and irrigation is proposed. Human factors such as agricultural technology innovation, policy mechanism guarantee and increase in farmland water conservancy construction investment can mitigate all kinds of negative impacts of climate warming on the Chinese agricultural water to a certain extent.

1. Introduction

Global climate change as a hotspot has been paid wide attentions by countries all over the world in the 21st century. The 2007 IPCC Fourth Assessment Report pointed out that global temperature has increased by 0.6 °C to 0.8 °C over the past century (Liu et al., 2012) which is the most dramatic increase in global temperature over the past 1000 years. Although the trends of Chinese climate change are consistent with the global ones, it has been more intense in designate areas. In China, extreme weather conditions such as heavy rain, strong thunderstorms and aridification are quite frequent, which undoubtedly poses the grim challenge to agricultural water and grain production. Both the United Nations Intergovernmental Panel on Climate Change and Food and Agriculture Organization rank agriculture industry as one of the most vulnerable to climate change, especially in the developing countries (Melkonyan and Asadoorian, 2013). Climate change has great impacts on water and soil resources supply in China, and affects the Chinese grain production. Especially under arid and semi-arid conditions, the impact of climate change on precipitation patterns is even greater than the combined effect of CO_2 concentration and temperature rise (Moss et al., 2010; Zhou, 2012). Although climate warming may lead to increased precipitation in some parts of China, the effective soil moisture will eventually reduce due to the increased water evaporation, resulting in crop drought and yield reduction (Murphy, 2009; Murphy et al., 2004). According to the simulated results, it is pointed out that climate change phenomenon will intensify in the coming 50 to 100 years, which will inevitably affect the agricultural irrigation water consumption and food safety in China.

It is of vital importance to assess the impacts of climate change on ecosystems, economies and societies, and propose the adapted policy options via the climate changes prediction (Naab and Koranteng, 2012; Todd et al., 2011). Agriculture is the source of people's basic subsistence, which is directly related to the survival and development of the human society. The impact of climate change on mankind is omnidirectional, multi-level and multi-dimensional, with both positive and negative effects. China's National Climate Change Program points out that the climate change has a major negative impact on the Chinese national economy, and the future Chinese grain production will face three major problems with the climate change. Firstly, grain production will become unstable and grain yield will intensely fluctuate. If appropriate measures are not taken, the output of the three major grain crops of rice, wheat and corn will decrease. Secondly, the cropping system will change as well as the grain production structure and distribution. Last but not the least, the agricultural production conditions will change, inducing the agricultural production cost greatly increasing.

* Corresponding author.
E-mail address: baixiao@zufe.edu.cn (X. Bai).

https://doi.org/10.1016/j.techfore.2019.01.015
Received 24 July 2018; Received in revised form 22 November 2018; Accepted 15 January 2019
Available online 22 March 2019

Therefore, it is of great significance to strengthen scientific researches in the relevant fields of climate change and enhance Chinese grain production ability for adaption, which is essential for food security, farmers' income and social stability. The assessment of the impacts of climate change has become one of the most important research fields around the world (Torquebiau, 2013; Unganai, 2009). The current researches are mainly confined to the natural sciences and the established crop models application in this field, in which the simulation and prediction results are based on the statistical analysis of experimental data. The relevant assessment methods are purely natural experimental, generally taking socio-economic factors into consideration (Fleischer et al., 2011; Lempert and Groves, 2010; Simelton et al., 2012). Presently, it is very urgent to analyze the impacts of climate change on grain production and its reverse adaptability. Researchers have recognized that grain production is not only affected by natural factors but also by various social and economic ones (Arshad et al., 2017; Challinor et al., 2010; Shang et al., 2017a). The impact of climate change on grain production also needs to be studied as an interdisciplinary subject of meteorology and economics. In the current researches on climate change in China, the field of natural sciences has not yet included the theories and methods of economics, as well as the study of climate change with economic methods lacks the meteorological support. The research focusing the impact of climate change is a crossing field with relative slow progress.

This paper attempts to address some unsolved issues of the current researches: with taking both natural and socio-economic factors into account, what is the impact of climate change (mainly temperature changes) on the Chinese grain production? What is the impact that water resource changes will bring to Chinese grain production and food security in the future? How great are the adverse effects of climate warming on agricultural production? How do we mitigate those negative impacts of climate change on agricultural production? This paper strives to achieve innovation and breakthrough in the above areas.

2. Data sources

The economic data for analysis of climate change impact on the grain yield mainly cover all provinces in China ranging from 1978 to 2008. The meteorological data mainly include the temperature and precipitation which are also recorded in all provinces and regions over the years, mainly obtained from the National Climate Center and Chinese Water Resources' National Key Laboratory on Watershed Water Cycle Simulation and Regulation and Hydropower Research Institute. Agricultural water resources data were obtained from "China Water Resources Bulletin" (1998–2005), "China Statistical Yearbook" (1998–2009), "China Agricultural Statistical Data Compilation" (1949–2004), "New China 55-year Statistical Compilation" (1949–2005), and "China Agricultural Yearbook" and "China Rural Statistical Yearbook" as well (Climate Change, 2007; People's Republic of China Ministry of Water Resources, 2008; The National Bureau of Statistics and The Rural Social and Economic Investigation Department, 2008).

Considering the significant regional differences of economic developments in China, the relationship between agricultural economic growth and water resources evolution in different regions could not be summarized by the same empirical rule. Therefore, this paper divides China into north, northeast, east, central, southwest, and northwest regions to carry out a respective investigation.

Based on the model analysis, this paper studies the impact on agricultural water use and grain production during the period from 1960 to 2006, and describes the climatic inter-annual change features through the Palmer drought severity index (PDSI). It quantitatively analyzes the impact of climate change on irrigation water and grain yield in different periods in China using scientific statistical methods, and establishes the relationship between agricultural irrigation water use per unit area and the Palmer drought index, pointing out the relative grain yield per unit area and drought index as well.

3. Empirical model structure

3.1. C-D-C model

Grain production is seriously affected by climate change. To explore ways to reduce the impacts of climate change on agricultural production, it is critical to link climate change with economic research. By considering the climate factors into the production function model of economics, the model accuracy can be improved to make the simulation results in accordance with the condition of agricultural production development under the climate change impacts. Simultaneously, the regional climate model and atmospheric circulation model (GCM) results can be used to simulate, test and forecast the future grain production.

The Cobb-Douglas production function (C-D production function) can be easily linearized, which will facilitate the establishment and calculation of the model (Saseendran et al., 2015). Taking logarithms of both sides, the relation is given by:

$$\ln Y = \ln a + b_1 \ln x_1 + b_2 \ln x_2 + b_3 \ln x_3 \tag{1}$$

Taking $y = \ln Y$, $a_0 = \ln a$, $X_1 = \ln x_1$, $X_2 = \ln x_2$, $X_3 = \ln x_3$.
Then the above equation becomes:

$$y = a_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 \tag{2}$$

The above model is a linear function model. By reconstructing it, we can observe the effect of changing input variables on the output. Specifically, take the natural logarithm of the output (y) and the three input variables, namely land (X_1), labor (X_2) and capital (X_3), and then carry out the regression analysis to its value in order to finally obtain the value of each parameter.

In the function model, there is no need for the dimensions among variables to be uniform when investigating the impact of independent variables on dependent ones. The parameters a, b_1, b_2 and b_3 are related to the economic significance of variables of each production factor, and are easy to be reached. For example, the labor force or the labor days can both be used as the amount of labor input, and the output value or output yield can both be used as output.

The elasticity values b_1, b_2, b_3 in the function model could objectively reflect the actual grain production. However, in practice, the C-D production function model does not often present high accuracy when fitting historical data. The reason is not enough scientific and accuracy of selected data is insufficient, but it is mainly because that the production process of the study object has generally a significant multi-structure, and different products have different function relationships between their inputs and outputs (Henstra, 2015; Marshall et al., 2012). Therefore, we can only get a set of comprehensive coefficients and a production function which can roughly describe the functional relationship, but cannot apply the C-D function to describe the exact relationship between grain production and three input parameters such as capital, labor and technology. Based on this, the original model is improved with a new built one, and many factors in this new model need to be discussed to simplify and abstract the role of a variety of them as much as possible.

The traditional production function model can describe the relationship between the production factors which are partially controllable and the limited quantities and the number of products, but ignores taking natural factors into account to improve the production function and enable it to reflect the relationship between input and output in an objective and scientific approach. Therefore, natural conditions, such as heat, light, water, terrain, soil and etc., become essential investments in agriculture (Esham and Garforth, 2013; Rosen and Guenther, 2015).

Based on these inputs, the agricultural output is available through the labor force input. With the development of social productive forces

Table 1
Model results reflecting the impact of climate change on rice yield in each region.

Independent variables	North China		Northeast China		East China	
	Coefficient	T value	Coefficient	T value	Coefficient	T value
LOG(TP)	−0.45***	−4.76	0.32***	5.22	−0.54***	−4.21
LOG(RF)	−0.003	−0.12	0.01	0.94	−0.02	−0.92
LOG(AC)	0.90***	37.02	0.89***	20.15	0.93***	13.84
LOG(LB)	0.08***	4.78	0.06***	2.78	0.08***	1.76
LOG(FT)	0.06***	4.11	0.08***	3.44	0.09***	3.67
LOG(AM)	0.08***	5.20	0.03***	2.78	0.07***	3.79
TE	0.07***	14.25	0.79***	42.56	0.08***	21.98
R^2	0.993		0.995		0.994	
$AdjR^2$	0.992		0.994		0.992	
F Test value	9336.7***		15,700.2***		448.5***	

Independent variables	Central China		Southwest China		Northwest China	
	Coefficient	T value	Coefficient	T value	Coefficient	T value
LOG(TP)	−0.63***	−7.03	−0.35***	−3.28	−0.49***	−3.78
LOG(RF)	−0.03	−0.02	−0.007	−0.41	−0.02	−0.85
LOG(AC)	0.85***	14.69	0.92***	12.36	0.88***	7.12
LOG(LB)	0.09***	3.92	0.10***	5.75	0.04***	2.27
LOG(FT)	0.06***	1.53	0.04***	2.87	0.03***	1.85
LOG(AM)	−0.02	−0.41	0.07***	4.75	0.02***	2.15
TE	0.76***	21.18	0.69***	30.92	0.79***	30.12
R^2	0.922		0.998		0.995	
$AdjR^2$	0.990		0.997		0.993	
F Test value	526.2***		2001.1***		505.2***	

Note: *** and ** respectively show that the impact is significant on the levels 1% and 5%.

and the improvement of economic level, the input proportion of production means in grain production gradually increases, and chemical fertilizers and pesticides can also promote agricultural output. In the modern agriculture, increasing investment in science and technology (such as cultivating improved varieties, opting for improved irrigation technology and working methods, etc.) has also become an important approach to the improvement of agricultural output (Lu et al., 2016a; Wang and Chen, 2016). Grain production is a combined process with natural and social production, which is exposed to the impacts of climate factors such as temperature and precipitation and to the introduction of chemical fertilizers, labor force and machinery, and technological progress as well (Fischer et al., 2007; Liu et al., 2013). This is added to the model as an important input factor to build a new "economy-climate" model, and can be called C-D-C model which can be used to analyze the impact of climate change on grain yield. The application of C-D-C model is a breakthrough for the traditional C-D production function model because it links both the economic and climate change impact analysis. Assuming that the model parameter reflecting the climate change factor is C, the expression of the new model is:

$$Y_i = X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} C^r \mu \tag{3}$$

X_1, X_2, and X_3 respectively represent the labor force, planting area and fertilizer input factors, β_1, β_2 and β_3 are the output elasticities of the above input factors. In the new model, β_1, β_2 and β_3 are used to distinguish b_1, b_2, b_3 in the traditional C-D production function, representing different output elasticities of different models. The parameter illustrating the climate change impact is C and the according output elasticity is γ. In the context of impacts of climate change on grain production, it mainly analyzes the impact brought by introducing the climate change factor C.

Grain production is related to natural conditions, material inputs, science and technology progress, thus production fluctuation is affected by both the climatic and socio-economic factors (Li et al., 2009). This paper presents the independent variables of the empirical model including the climate and grain production input variables, where the climate ones select the average temperature and average precipitation during the growing period of rice, and the grain production input ones define the planting area of rice or rice acreage, the number of agricultural labor force, the agricultural chemical fertilizers introduction, total power of agricultural machinery and so forth.

Based on the above explanatory variables, this paper constructs an empirical C-D-C model as follows.

$$\ln Y_{it} = a_0 + b_1 \ln(TP_{it}) + b_2 \ln(RF_{it}) + b_3 \ln(AC_{it}) + b_4 \ln(LB_{it}) + b_5 \ln(FT_{it}) + b_6 \ln(AM_{it}) + b_7 TE + v_{it} \tag{4}$$

In the model, i and t represent year t in area i; Y_{it} represents the rice yield; TP represents the mean temperature during the growing period of rice; RF is the average precipitation during the growing period of rice; AC represents the rice acreage; LB stands for the labor force engaged in the production of rice; FT is the amount of fertilizers introduced in rice production; AM symbolizes the total power of agricultural machinery in rice production; and TE reflects the technological progress impact.

Because the paper aims to show the impacts of climate change on water resources and grain production, we will only analyze the impact of climate change on rice production in this section.

3.2. Model results analysis

Based on the above empirical model of the impact of climate change on rice yield, the statistical data adopted in this paper come from the climatic data of 160 sites provided by the National Climate Center. Data are only updated to the year of 2000, so this paper conducts analysis accounting for the statistical data from 1968 to 2000. The Eviews Software was used to carry out multiple regression analysis on six regions of North China, Northeast China, East China, Central China, Southwest China and Northwest China. Table 1 shows the model regression results for the impact of climate change on rice yield in each region.

From Table 1, it is obvious that the simulation results of each model are generally good and R^2 and $AdjR^2$ values are higher than 0.99, indicating that the model's explanatory ability is more than 99%, so the

control variables of the rice acreage, labor input, fertilizers introduction, total power of agricultural machinery, technological progress etc. plus climate variables can explain each region's 99% of rice production.

Each F value is large, and all of the values pass the significance test at the level of 1%. Therefore, the common impact of each factor on rice yield is significant in each model. As one of the climatic factors to be considered in the model during the growing period of rice, the average temperature passes the significance test at the level of 1%, and in addition to the Northeast China region, the coefficients of all of other regions are negative, which means that the climate change has a negative impact on rice yield in most parts of China, and the Chinese grain production is unfavorable. The conclusions drawn from the model analysis basically coincide with the research results of the literature (Zhou et al., 2010) which analyzes the impact of temperature change on rice yield during the growing season of rice in main rice production areas in China by studying the relationship between temperature change and climate signals of yield during the period from 1981 to 2000. The results shows that temperature rise had a positive impact on the rice yield in Northeast China over the past 20 years, but presented an adverse impact in the double cropping rice production area in the south of the Yangtze River basin, which is also close to the reality.

3.3. The impact of climate on rice yield

As one of the climatic factors during the growing period of rice in the model, the mean temperature passes the significance test at the level of 1%, and in addition to the Northeast China region, the coefficients of all of other regions are negative, which indicates that temperature rise has an adverse impact on the rice yield. The main reason for variation in temperature to improve the rice yield is that the temperature will accelerate the growth and development of crops, shorten their growing period and reduce the accumulating time of dry matter, thus reducing the total dry weight of crops and consequently causing a fall in the final yield.

There exists a great difference among the average temperatures in each region, inducing the different extent of impact of temperature change on rice yield. This paper respectively calculates the extent of this impact on the rice yield in each region when the average temperature rises by 1 °C. Firstly, according to the regression results of the model, adopt the average temperature during the growing period of rice, and predict the grain yield when other variables remain constant (average number). Then, predict the average grain yield by increasing PC based on the average temperature and keeping other variables constant (average number), and compare the two predicted yields. Finally, the impact of 1 °C temperature rise on the grain yield will be obtained. The results show that there is a significant regional difference in the decrease of rice yield when the average temperature rises of 1 °C in different regions of China. The largest decrease is observed in Northwest China with 2.8% reduction; next is the South Central China region where the rice yield decreased by 2.6%; the next are the East and North China regions where the rice yields decreases by 2.4% and 2.3% respectively; the decrease in the Southwest China is the smallest and presents 1.9% decrease accounting for the same average temperature rise of 1 °C.

The difference among each region is not only related to the difference between the natural environment and agricultural production conditions in each region, but also reflects the regional differences in the ability to adapt to climate change to a certain extent. Since the 1990s, the rice acreage has continued to expand in Northeast China, particularly in Heilongjiang Province, and the rice yield keeps increasing, which is directly related to climate warming. Due to significant climate warming, the rice planting areas in Northeast China expand to the north, and rice can now be grown in Yichun and Heihe areas where it could not be planted in the past (Shang et al., 2017b).

The natural conditions of the Northwest region are relatively harsh, and the level of socio-economic development and agricultural production conditions are poor. In the case of rising temperature, the Southern region can develop water-saving agriculture to find a remedy for the adverse impact of climate warming. However, precipitation is very rare in the Northwest, causing severe water shortages; besides, both economic and technological development levels are not good. Therefore, in case the average temperature rises, adaptive measures are relatively limited to be conducted, so the impact of temperature rise on rice yield is the most significant.

The South, Central and East China have better economic development conditions and are quoted with higher level of science and technology and the richest water resources. Although the temperature rise is also significant, climate change can be mitigated by improving the crop varieties and developing water-saving agriculture, and its impact is relatively mild compared with that recorded in the northwest region. The economic development is good in the Northern China, and the temperature rise is obvious over the past several decades, reaching the rate of rise of 3.3 °C per decade. Similar to the northeast region, the double-cropping area of rice expands northward due to the temperature rise, which positively affects the production of rice in North China. However, due to the lack of water in this northern region, and due to the fact that the average annual precipitation is less than 500 mm in many areas, the favorable factors such as increase of multiple cropping index brought by temperature rise cannot be into full play due to limited water resources. Therefore, the temperature rise adversely impacts on rice production. The southwestern region is different from other regions; this is confirmed by its annual average temperature rise which is recorded to be very small over the past few decades. Besides, its natural conditions are more favorable, mainly in the temperate and subtropical climates with relatively good climate conditions and relatively high rainfall, therefore, the temperature rise effect is not harsh to the rice production (Lu et al., 2016b; Raymond and Robinson, 2013).

4. Effect of water resource constraints on agricultural production

4.1. Effect of water resource constraints on agricultural yields

According to the research results, there is a negative correlation between water shortages and crop yields (Sun et al., 2012). Referring to water resources shortage, the author divides the sample villages into with water shortage and without water shortage. By comparing the crop yields of two different villages, it is obvious to find out that yields are higher in those villages where there is no shortage of water because there are more abundant water resources, than in those villages short of water resources. The maize yield per unit of water shortage in villages is 5355 kg/hm^2, which is 9% lower than the yields produced in villages with no water shortage (Table 1). Similarly, the difference in wheat yields between the two groups is 11%.

4.1.1. Econometric model setting

There are many factors which affect crop yields per unit area in different aspects. In order to control the impact of these factors and deeply analyze effects of water shortages thereon, this paper analyzes the relationship between water resources and agricultural economic growth. This is a method which firstly appeared in Holtz-Eakin's research, and which has upgraded the model to obtain the following econometric one:

$$Y_{kit} = \alpha + \beta W_{it} + \delta Z_{it} + \eta N_{it} + \gamma T_{it} + \varphi D_{it} + \varepsilon_{kit} \tag{5}$$

In the above formula, Y_{kit} is the per unit area crop yield k during the period t in the village i, mainly including wheat and corn; i is a village; k is the crop type; t is the period (1990 and 2000); W_{it} is the condition for water resources shortage during the period t in the village i and is an explanatory variable; Z_{it} stands for the social and economic characteristics of the village i during the period t; N_{it} represents the natural condition characteristics of the village i during the period t, mainly including gradient and soil type; T_{it} signifies the dummy time variable,

represented by 1990 and 2000; D_{it} is the dummy regional variable; α , β , δ , η, γ and φ are the estimable parameters; and ε_{kit} represents the random disturbance term.

In the model, Z_{it} represents the social and economic characteristics of the village i during the period t. The author chooses the scale of the farmer's household, the per capita arable land or farmland area, the proportion of non-agricultural employment labor force, educational level and market development status as the main indexes to reflect the social and economic situation of peasants.

The household scale refers to the average number of people in each household. It is the quotient of the total population of a village divided by the total number of households existing therein. The per capita farmland is the quotient of the total arable area in the village divided by the village population. The proportion of non-agricultural employment labor force is the quotient of the total number of non-agricultural employees divided by the total number of working people, where the non-agricultural employees include people working in other non-agricultural fields inside and outside the village. The educational level is represented by the proportion of the labor force with primary school level and above in the total labor force. The higher the proportion, the higher the educational level in the village.

The market development is represented by the distance from the village committee to the county government (in km), and the closer the distance explains the better market conditions on behalf of the village. N_{it} is the natural condition for the village i during the period t, mainly including gradient and soil type. Because the proportion of sand is all 0 within the considered sample villages, the author takes clay as a reference, and uses the proportion of loam to present the soil type.

In the above yield per unit area model, the sample villages selected for wheat are the ones in which wheat is to be grown (340 villages and 680 observation values) for two years to constitute standard panel data. In the model, the dummy time and dummy regional variables are introduced to control the impact of technological advances and inter-regional differences on the crop yields per unit area. Same as the case of wheat, the villages in which corns are grown for two years (454 villages and 908 observation values) are selected as sample villages to constitute the standard panel data. Similarly, the dummy time and dummy regional variables are introduced in the model.

4.1.2. Quantitative estimation results

The established econometric model was used to analyze the impact of water shortages on crop yields. It can be seen from the Table 3 that the R2 values of wheat and corn regression results are 0.16 and 0.4 respectively, and the model better suits for the panel data. Many of the control variables are statistically significant, and the signs of the coefficients come as it was expected. In the yield models for wheat and corn, the impact of non-agricultural employment on both of the crops' yields is significant and negative, which indicates that the higher the proportion of non-agricultural employees, the lower the yield of wheat and corn. The effects of gradient on the two crops are all significantly adverse, indicating that the steeper the gradient, the lower the yields of wheat and corn, which confines with expectations of the research. In addition, it can also be seen that the effects of time dummy variables on the both crops' yields are significant, and the signs are all positive, hence, with the extra-time due to technological advances, changes in inputs and other factors, both wheat and corn yields increase.

Consistent with the results of the descriptive statistical analysis, wheat and corn estimation results show that there is a significantly negative impact on both of the crops' yields under water resource constraints. As it can be seen from Table 2, water shortages have a significant impact on wheat and corn yields per unit area, and the sign is negative, which means that water shortages have a significantly negative impact on the yields of these two crops. The model estimation results show that the yield of wheat will decrease by 274 kg/hm^2 and that of corn by 263.4 kg/hm^2, indicating that wheat is the mostly affected.

Table 2
Effect of water shortage on crop yield per unit crops (kg/hm^2).

Water resources status	Wheat	Corn
No shortage	4290	5873
There is shortage	3818	5355

Note: Data are obtained from the research data of China Water Resources and Hydropower Research Institute.

Table 3
Effects of water resources on crop planting structure.

Water resources status	Proportions of the planting areas					
	Wheat	Corn	Rice	Cotton	Others	Total
No shortage	27	35	13	4	21	100
There is shortage	27	38	8	3	24	100

Note: Data are obtained from the research data of China Water Resources and Hydropower Research Institute.

4.2. Effects of water resource constraints on agricultural planting structure

Water resource constraints also affect the crops' planting structure. If water supply is in good condition and there is no shortage, farmers are more concerned with planting more water-intensive crops, and they will particularly increase the rice acreage (Lu et al., 2016c). the area under which rice is to be planted. if there is no water resources shortage, the rice acreage proportion accounts for 13% of the total planting area for all of the crops, while in water-scarce villages, the rice acreage makes up only 8%, 5% lower than the proportion of the entire crop acreage as compared to the villages where there is no shortage of water (Table 4). In addition to rice, the cotton acreage proportion will also be slightly lower if water supply is insufficient (1% deficit). In contrast to rice and cotton, the corn acreage proportion is much higher (3% higher) in water-scarce villages, which indicates that corn is grown at a higher rate because it is a crop which is less dependent on irrigation water supply. In addition, the wheat acreage proportion is always 27% whether there is water shortage or not, indicating that planting wheat may not be significantly affected by water scarcity from a descriptive statistical analysis.

4.2.1. Model setting

For the situation of water shortage impact on the crop planting structure, the following econometric model is established according to the relevant economic theory:

$$C_{kit} = \alpha + \beta W_{it} + \delta Z_{it} + \eta N_{it} + \varphi D_{it} + \varepsilon_{kit} \tag{6}$$

In the above formula, i is a certain village; k is the crop type; t is the period (1995 and 2005); C_{kit} represents the crop planting structure, which refers to the crop k acreage proportion as compared to the total planting area during the period t within the village i, mainly including wheat, corn, rice and cotton. The water shortage condition in the village i during the period t is W_{it}, which is an explanatory variable that is mostly concerned by authors. α, β, δ, η, γ, φ are the estimable parameters; and ε_{kit} is the random disturbance term. All control variables are basically the same as the model (1).

In the model (2), there are 538 villages and 1076 observed values which constitute the standard panel data. In addition to rice, wheat, corn and cotton in the model, other crops' acreage refers to the proportion in the total planting area. Carry out the regression using the Seemingly Unrelated Regression method which can control the impact of multiple factors on the regression variables.

4.2.2. The measurement estimation results

The measurement estimation results of the impact of water

Table 4
Estimated results for the impact of water resources on crops yields per unit area.

Influencing factors	Rice	Wheat	Corn	Cotton
Water resource conditions	−0.011(1.87)*	−0.0004(0.05)	0.014	−0.003
0 = No; 1 = Yes			−1.33	−0.69
Per capita farmland	−0.022(0.82)	0.0003	−0.013(3.35)***	0.003
(hm/person)		−0.08		(2.05)**
Per capita population	−0.00001(0.03)	0.0004	0.001(2.06)**	−0. 000 03
(Person/household)		−0.99		−0.15
Non-agricultural labor force	0.069(1.76)*	0.01	−0.113(1.08)*	0.011
Proportion (0–1)		−0.19		−0.46
Primary school or above	0.047(3.37)***	−0.027	−0.034(1.54)	0.000 2
Horizontal proportion (0–1)		−1.39		−0.02
Distance from the village committee to the county government	0. 000 5	0.001	−0.001(3.18)***	0.000 06
	(2. 53)**	(4.77)***		−0.46
Loam proportion (0–1)	−0.769	−0.034	−0.007(0.75)	0.004
	(19.69)***	(5.09)***		−1.05
2004	−0.02	−0.063	0.37(5.95)***	−0.034
(Time dummy variable)		(7.56)***		−1.34
Regional dummy variable	Ignored	Ignored	Ignored	Ignored
Constant	0.638(33.79)***	0.049(1.16)*	0.085	−0.019
			(2.81)***	−1.48
R^2	0.86	0.75	0.65	0.75
Number of Observed Values	1081	1069	1076	1072

Note: *** and ** respectively represent that impact is significant on the levels 1% and 5%.

shortages on crop structure are shown in the Table 5. According to the regression results, the model has a better degree of fitting, where R^2 is above 0.65. The estimation results show that many of the control variables are statistically significant, and the signs of the coefficients do not diverge from expectations. For example, in the wheat acreage proportion model, the loam ratio has a significant and positive impact, which indicates that the higher the proportion of loam, the higher the proportion of wheat acreage. In the corn acreage proportion model, the per capita arable land has a significant impact on the corn acreage proportion, and the sign is negative, indicating that the smaller the per capita arable land, the higher the corn acreage proportion. Considering the rice acreage proportion model, the impact of educational level on the rice acreage proportion is significant and positive, which means that the higher the educational level, the higher the paddy rice acreage proportion.

Consistent with the descriptive statistical analysis results, the impacts of water shortage on the different crops' acreage proportion are different. In the rice acreage proportion model, the water resources shortage has a significant impact on the rice acreage proportion and the sign is negative. However, in the acreage proportion models for wheat, corn and cotton, water scarcity impact is not significant, which is basically consistent with the descriptive statistical analysis results. According to the model's estimation results, if there is shortage in water resource, the rice acreage proportion will decrease by 1.2%, while the acreage proportions for wheat, corn and cotton and other crops will not experience a significant change.

5. Analysis of the correlation between climate change, water resources and grain yield

5.1. Analysis of the correlation between climate change and grain yield

Both climate change and human are factors that affect the grain yield per unit area (Bryan et al., 2013). In order to quantitatively study the impacts of climate change on rice yield per unit area, and according to the climate change characteristics, in the results of the correlation analysis between the Palmer Drought Severity Index (PDSI) and per-hectare grain output (PHGO) show that there was a good linear correlation between PHGO and PDSI during the period from 1960 to 2000 (See Fig. 1). Based on this correlation, a linear regression equation between PHGO and PDSI is established as follows:

$$PHGO = -1094.4\ PDSI + 1668$$

The coefficient of the linear regression equation is 0.7611, and the

Table 5
Estimated results of the impact of water resources on crop yields.

Influencing factors	Wheat	Corn
Per capita arable land under water shortage/(kg·hm^{-2})	−273.9(2.37)**	−261.4(1.97)*
(hm^{2}·人 − 1)	−0.43(0.16)	5.78(1.70)*
Per capita arable land/(hm^2 people − 1)		
The average population/(people · households − 1)	−4.5(1.19)	1.7(0.34)
Proportion of non-agricultural labor force	−20,014.9(2.95)***	−4052.2(4.99)***
Proportion of primary school level or above the cultural level	−355.1(1.34)	479.8(1.45)
Distance from the village committee to the county government (km)	−4.2(1.30)	2.2(0.66)
Gradient/degree	−226.4(4.10)***	−1131.1(1.9)*
Loam proportion (0–1)	−56.3(0.24)	−878.7(2.93)***
2005 (Time dummy variable)	1176.7(13.18)***	13,878.6(14.81)***
Regional dummy variable	Ignored	Ignored
Constant	4751.1(19.06)***	4976.2(11.26)***
R^2	0.14	0.24
Number of Observed Values	682	911
Number of villages	343	455

Note: 1. "*", "**" and "***" represent the significance level of 10%, 5% and 1% respectively; and descriptive statistical analysis of the results.
Note: 2. The value in the bracket is *t* value and the result of descriptive statistical analysis.

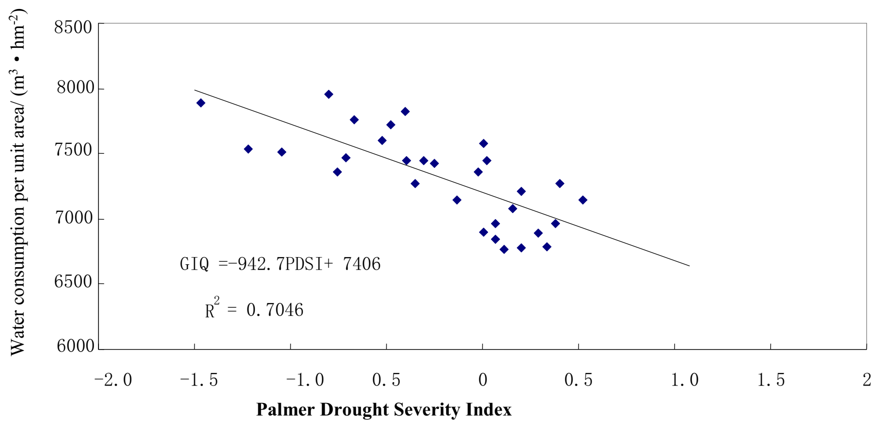

Fig. 1. Analysis of the correlation between grain yield per unit area and Palmer Drought Severity Index (PDSI)

independent variable is PDSI, which is a climatic factor, while PHGO represents the dependent variable. Therefore, it can be considered that climate factors played a dominant role in rice production during the period from 1960 to 2000, and human factors of technological progress, policy mechanisms, agricultural production inputs, etc. played a relatively minor role in this era. This basically coincides with the technology development reality regarding the improvement of the main rice crop varieties, farmland irrigation, extensive use of chemical fertilizers and pesticides, and with the implementation of the household contract responsibility system with remuneration linked to the output in rural areas, which is closely related to the sustainable increase in agricultural production.

Numbers show that after 1984, the actual value of PHGO is far greater than its expected value, and the maximum error occurred in 1993, reaching 1708 kg/hm^2. The comprehensive analysis shows that during the period from 1984 to 2000, the share of the impact of climate change on rice yield decreased gradually, which means that the rice production ability to respond to climate change was gradually strengthened, and this was mainly due to human factors such as technological progress, policy mechanisms, great increase in agricultural production input and son forth.

During the period from 1984 to 2000, the average increase of rice yield per unit area under the impact of the above mentioned human factors was 1170 kg/hm^2, and the maximum value was 1708 kg/hm^2 in 1993; in the same year the average increasing rate of yield per unit area of paddy rice was 42.95%, and the maximum value was 70.48%, which indicates that the yield benefit was very significant. Besides, it also reflects that the climate change has caused the Chinese grain yield per unit area to decrease by more than 1000 kg/hm^2. The results showed that the negative impacts of climate warming on rice production could be alleviated to a certain extent through human factors such as innovation of the used technology, guarantee of the policy mechanisms and increase in agricultural production input.

5.2. Analysis of the correlation between water resource and grain yield

Based on the analysis of the impact of water resource constraints on the agricultural yields per unit area and the planting structure, and by considering the climate change characteristic (Marshall et al., 2009; Zinyengere et al., 2011) it is found in the analysis of the correlation between the Palmer Drought Severity Index (PDSI) and the grain yield per unit area (FP) that there was a good linear correlation between GIQ and PDSI during the period from 1960 to 2000 (See Fig. 2). Based on this correlation, a linear regression equation between GIQ and PDSI is established as follows:

$$FP = PDSI - 942.7 + 7406$$

The coefficient of the linear regression equation is 0.7064, and the independent variable is PDSI, which is a climate factor, while the dependent variable is the grain yield per unit area (FP). Therefore, it can be confirmed that during the period from 1960 to 2000, the impact of climate factors on agricultural water use was dominant, and the human factors played a relatively small role during this period. This was consistent with the actual development of agricultural water use. Simultaneously, the linear regression equation is used to calculate the predicted FP from 1960 to 2000.

Numbers show that the actual value of FP was far smaller than its predicted value after 1990, which means that the grain yield per unit area predicted by the climatic factors is far greater than the actual value, and the maximum error occurred in 2000, reaching 2444 m^3/hm^2. It can be seen from the comprehensive analysis that the share of climate change impact on grain yield per unit area declined gradually during the period from 1990 to 2000, which indicates that the agricultural water ability to respond to climate change substantially increased mainly due to the human factors such as water saving technology progress, policy mechanism guarantee and great increase in input of irrigation water conservancy projects. It can be obtained, by multiplying the effective irrigation areas that compared to the control level of 1960–2000, that the annual average value of the agricultural water saved by human factors (water-saving technological progress, policy mechanisms, irrigation and water conservancy projects, etc.) was 139.4 billion m^3, the average water-saving ratio was 27.22%, and the maximum value was 43.13% in 2000, which implied a significant benefit. Besides, the average of increase in grain yield per unit area caused by climate change exceeded 100 billion m^3. The results also indicated that the negative impact of climate warming on agricultural water use can be mitigated to a certain extent by the human factors such as water-saving agricultural technology innovation, policy mechanisms guarantee and increase in input of water conservancy projects.

6. Conclusions

(1) Climate change has become an important factor affecting agricultural water use and grain production in China. During the period from 1960 to 2000, Climate change characteristics of China were analyzed via Palmer Drought Severity Index (PDSI), which indicated that the drought trend was relatively moderate before the 1990s, and it was more severe after this period. As a result of climate change, irrigation water consumption experienced an average increase of more than 100 billion m^3, the grain yield per unit area decreased by more than 1000 kg/hm^2 on average in China.

(2) Climate change has a significant impact on rice production. During the temperature rise periods, it had a significant negative impact on rice yield outside Northeast China and there were significant regional differences in the impact of temperature rise on rice yields.

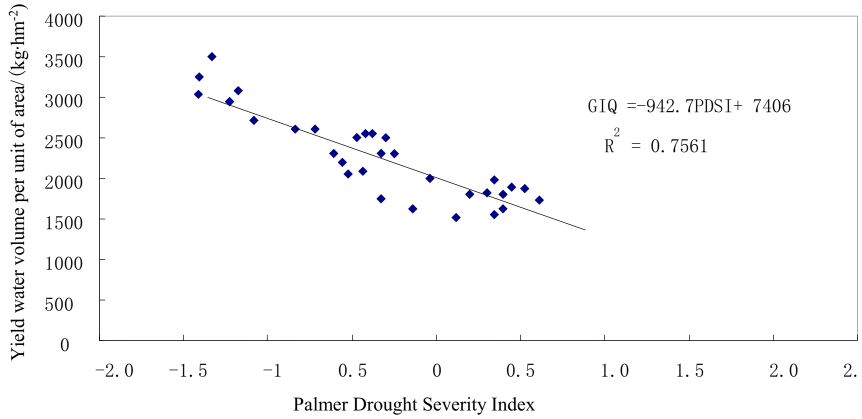

Fig. 2. Analysis of the correlation between grain yield per unit area and Palmer Drought Severity Index (PDSI).

The decrease of rice yield was different as compared with the rise in average temperature in all regions. Firstly, there is a greater decline in Northwest China; followed by that in the Central and Southern China region; the thirdly placed is East China and North China, and the smallest decline is found in the Southwestern Region. In addition to the regional differences between the natural environment and agricultural production conditions, it also reflects the differences of all of the regions' ability to adapt to climate change to a certain extent.

(3) There is an obvious difference in the relationship between water resources and agricultural economic growth in different regions. In the eastern region, there is a short term two-way causal relationship between water resources and agricultural economic growth, and a long run one-way causal relationship exists between the two factors. In the central region, there is a short term one-way casual relationship between water resource and agricultural economic growth, while there is a long term two-way causal relationship between the two factors. In the western region, there is short term and long term only one-way causal relationship between above mentioned factors.

Conflict of interests

The authors declared that they have no conflict of interests to this work.

Acknowledgment

This research was supported by Zhejiang province Funds for Distinguished Young Scientists (Grant No.: LR15E090002) and Zhejiang Provincial Natural Science Foundation (Grant No: LQ18E090004, LQ16E080006).

References

Arshad, M., Amjath-Babu, T.S., Krupnik, T.J., et al., 2017. Climate variability and yield risk in South Asia's rice–wheat systems: emerging evidence from Pakistan[J]. Paddy Water Environ. 15 (2), 249–261.
Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., Herrero, M., 2013. Adapting agriculture to climate change in Kenya: household strategies and determinants. J. Environ. Manag. 114, 26–35.
Challinor, A.J., Simelton, E.S., Fraser, E.D.G., Hemming, D., Collins, M., 2010. Increased crop failure due to climate change: assessing adaptation option susing models and socio-economic data for wheat in China. Environ. Res. Lett. 5 (3).
Climate Change, 2007. Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge.
Esham, M., Garforth, C., 2013. Agricultural adaptation to climate change: insights from a farming community in Sri Lanka. Mitig. Adapt. Strateg. Glob. Chang. 18, 535–549.
Fischer, Günther, et al., 2007. Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080. Technol. Forecast. Soc. Chang. 74, 1083–1107.
Fleischer, Aliza, Mendelsohn, Robert, Dinar, Ariel, 2011. Bundling agricultural technologies to adapt to climate change. Technol. Forecast. Soc. Chang. 78, 982–990.
Henstra, D., 2015. The tools of climate adaptation policy: analysing instruments and instrument selection. Clim. Pol. https://doi.org/10.1080/14693062.2015.1015946.
Lempert, Robert J., Groves, David G., 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. Technol. Forecast. Soc. Chang. 77, 960–974.
Li, Y., Ye, W., Wang, M., Yan, X., 2009. Climate change and drought: a risk assessment of crop yield impacts. Clim. Res. 39, 31–46.
Liu, Z., Yang, X., Hubbard, K.G., Lin, X., 2012. Maize potential yields and yield gaps in the changing climate of northeast China. Glob. Chang. Biol. 18, 3441–3454.
Liu, Z., Hubbard, K.G., Lin, X., Yang, X., 2013. Negative effects of climate warming on maize yield are reversed by the changing of sowing date and cultivar selection in Northeast China. Glob. Chang. Biol. 19, 3481–3492.
Lu, S.B., Zhang, X.L., Wang, J.H., 2016a. Impacts of different media on constructed wetlands for rural household sewage treatment. J. Clean. Prod. 127, 325–330.
Lu, S.B., Zhang, X.L., Pei, L., 2016b. Influence of drip irrigation by reclaimed water on the dynamic change of the nitrogen element in soil and tomato yield and quality. J. Clean. Prod. 139 (15), 561–566.
Lu, S.B., Wang, J.H., Pei, L., 2016c. Study on the effects of irrigation with reclaimed engineering. Int. J. Environ. Res. Public Health 13, 298–306.
Marshall, N.A., Marshall, P.A., Tamelander, J., Obura, D., Malleret-King, D., Cinner, J.E., 2009. A Framework for Social Adaptation to Climate Change; Sustaining Tropical Coastal Communities and Industries. IUCN, Gland, Switzerland.
Marshall, N.A., Park, S.E., Adger, W.N., Brown, K., Howden, S.M., 2012. Transformational capacity and the influence of place and identity. Environ. Res. Lett. 7 (9), 034022.
Melkonyan, A., Asadoorian, M.O., 2013. Climate impact on agroeconomy in semiarid region of Armenia. Environ. Dev. Sustain.
Moss, R., Edmonds, J., Hibbard, K., Manning, M., Rose, S., van Vuuren, D., Carter, T., Emori, S., Kainuma, M., Kram, T., Meehl, G., Mitchell, J., Nakicenovic, N., Riahi, K., Smith, S., Thomson, R.S.A., Weyant, J., Wilbanks, T., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–756.
Murphy, J., 2009. UK Climate Projections Science Report: Climate Change Projections. (Met Office Hadley Centre technical report).
Murphy, J.M., Sexton, D.M.H., Barnett, D.N., Jones, G.S., Webb, M.J., Collins, M., Stainforth, D.A., 2004. Quantification of modelling uncertainties in a large ensemble of climate change simulations. Nature 430, 768–772.
Naab, J.B., Koranteng, H., 2012. Using a gender lens to explore farmers adaptation options in the face of climate change: results of a pilot study in Ghana. In: Working Paper No. 17, CGIAR Challenge Program on Climate Change, Agriculture and Food Security. CGIAR, Rome.
People's Republic of China Ministry of water resources, 2008. China Water Resources Bulletin, 2007. China Water Power Press.
Raymond, C.M., Robinson, G.M., 2013. Factors affecting rural landholders' adaptation to climate change: insights from formal institutions and communities of practice. Glob. Environ. Chang. 23, 103–114.
Rosen, Richard A., Guenther, Edeltraud, 2015. The economics of mitigating climate change: what can we know? Tech. Forcasting Soc. Chang. 91, 93–106.
Saseendran, S.A., Ahuja, Lajpat R., Ma, Liwang, 2015. Developing and normalizing average corn crop water production functions across years and locations using a system model. Agric. Water Manag. 157, 65–77.
Shang, Yizi, Lu, Shibao, Li, Xiaofei, et al., 2017a. Balancing development of major coal bases with available water resources in China through 2020. Appl. Energy in press. (Corrected Proof, Available online 9 July 2016).
Shang, Y.Z., Lu, S.B., Shang, L., Li, X.F., Shi, H.W., Li, W., 2017b. Decomposition of industrial water use from 2003 to 2012 in Tianjin, China. Technol. Forecast. Soc. Chang. 116, 53–61.
Simelton, E., Fraser, E.D.G., Termansen, M., Benton, T.G., Gosling, S.N., South, A., et al., 2012. The socioeconomics of food crop production and climate change vulnerability: a global scale quantitative analysis of how grain crops are sensitive to drought. Food Sec. 4 (2), 163–179.
Sun, Y., Zhou, H., Wang, J.Y., 2012. Farmers' response to agricultural drought in paddy field of southern China: a case study of temporal dimensions of resilience. Nat.

Hazards 60 (3), 865–877.
The National Bureau of statistics, the rural social and Economic Investigation Department, 2008. China Agriculture Statistical Yearbook. China Statistics Press, Beijing, pp. 2007.
Todd, M.C., Taylor, R.G., Osborn, T.J., Kingston, D.G., Arnell, N.W., Gosling, S.N., 2011. Uncertainty in climate change impacts on basin-scale freshwater resources - preface to the spetial issue: the quest-gsi methodology and synthesis of results. Hydrol. Earth Syst. Sci. 15, 1035–1046.
Torquebiau, E., 2013. Agroforestry and climate change. In: FAO Webinar, CIRAD–Agricultural Research for Development, 5 Feb 2013.
Unganai, L.S., 2009. Adaptation to climate change among agropastoral systems: case for Zimbabwe. Earth Environ. Sci. 6, 412–425.
Wang, Saige, Chen, Bin, 2016. Energy–water nexus of urban agglomeration based on multiregional input–output tables and ecological network analysis: a case study of the Beijing–Tianjin–Hebei region. Appl. Energy 178, 773–783.
Zhou, Y., 2012. Syngenta foundation for sustainable agriculture. In: BIT 2nd conference on Agriculture, Dalian, China. (personal contact).
Zhou, H., Wang, J., Wan, J., et al., 2010. Resilience to natural hazards: a geographic perspective. Nat. Hazards 53, 21–41.
Zinyengere, N., Mhizha, T., Mashonjowa, E., Chipindu, B., Geerts, S., Raes, D., 2011. Using seasonal climate forecasts to improve maize production decision support in Zimbabwe. Agric. For. Meteorol. 151, 1792–1799.